## Research Highlight

The parameterization of air vertical velocity within cumulus clouds in large-scale models has been a subject of active research. The mean vertical velocity in convective clouds is desired for several reasons. For example, it is needed to determine the cloud-top height. Traditionally, the neutral buoyancy level (NBL) is defined as the cloud top in most early convection schemes. However, the actual cloud top is typically higher than the NBL, because the cloud parcel can still travel some distance before its velocity completely vanishes, creating the so-called overshooting region. To parameterize overshooting of cumulus convection, it is necessary to introduce in-cloud vertical velocity equation. Furthermore, vertical velocity is needed to calculate cloud nucleation and the falling velocity of precipitation. In addition, many shallow convection schemes calculate the mass fluxes of the plumes. Thus, when the vertical velocity is known for an entraining plume, the fractional area of the plume can be derived.

One source of the difference in the published literature of the velocity is the precise definition of the plume in shallow convection. Some studies defined it as the fraction of positively buoyant upward fraction of air that contains condensed water, which is referred to as convective core. Others defined it as upward fraction of air that contains condensed water without the positive buoyancy condition, referred to as updraft. In almost all schemes, the cloud fraction is considered to be the same as the plume, even though cloud area may be negatively buoyant and in a downward motion.

The purpose of this paper is to evaluate the vertical momentum budget and to derive parameterizations of the mean velocity separately for the three types of plumes: convective core, convective updraft, and cloud plume. Most current parameterization schemes of shallow convection only use one plume type in which fractional area of a plume is assumed to be the same as the cloud amount. However, more than one plume type may be needed to describe different roles of cumulus convection. For example, convective core is more relevant to cloud nucleation and the cloud-top height, while convective updraft is more relevant to precipitation, and cloud plume is more relevant to radiation. The present study addresses the parameterization of vertical velocity in the different plume types.

Four shallow cumulus case studies, including three equilibrium marine cases and one transient continent case, are simulated by using the System for Atmospheric Modeling (SAM) large-eddy simulation (LES) model to investigate the budget terms of plume vertical velocity for convective cores, updrafts and clouds. For the cloud core, results show that the mean vertical velocity is primarily governed by acceleration of buoyancy forcing and sub-plume turbulence in the upper layer, and deceleration by the pressure gradient force and entrainment drag. The pressure perturbation and sub-plume turbulence are found to compensate each other significantly in the upper layer, leading to a small sum that is proportional to either buoyancy forcing or entrainment term, which forms the physical basis of the vertical velocity parameterization by using the buoyancy forcing and the entrainment drag. For the cloud updraft, the upward momentum source is significantly contributed by the subgrid transport and the entrainment term, particularly in the upper cloud layer. For the cloud plume, the buoyance term is a momentum source only in the lower cloud layer. In the upper layer, the subgrid vertical transport is the dominant source.

Momuntum budget analysis from LES models showed that the Simpson and Wiggert (1969) equation is generally valid for the different convective types of cores, updrafts, and clouds as long as appropriate scaling coefficients are used. A least error analysis is applied to obtain the optimal values for the scaling factors of and in the for each types of plumes. It is shown that the parameterization can accurately describe the vertical profiles of the mean plume velocity as long as the scaling coefficients are
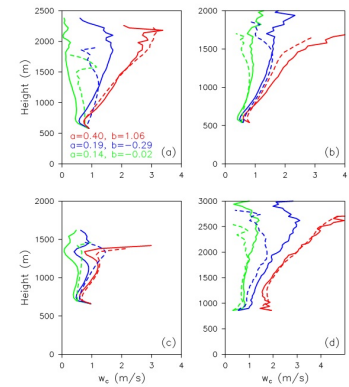
Mean profiles of vertical velocity in convective cores (red); convective updrafts (blue); and convective cloudy areas (green) from large-eddy simulations (solid) and parameterizations (dash): (a) Rain in Cumulus over the Ocean (RICO); (b) Barbados Oceanographic and Meteorological EXperiment (BOMEX); (c) Atlantic Trade-Wind EXperiment (ATEX); and (d) ARM-SGP. (Units: ms-1).

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used differently for different types of plumes. These coefficients are given in the paper for convective core, convective updraft, and cloud plumes.

Reference(s)
Wang X and M Zhang. 2014. "Vertical velocity in shallow convection for different plume types." Journal of Advances in Modeling Earth Systems, 6(2), doi:10.1002/2014MS000318.

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